GEANT4 simulations of the n_TOF spallation source

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The n_TOF Collaboration

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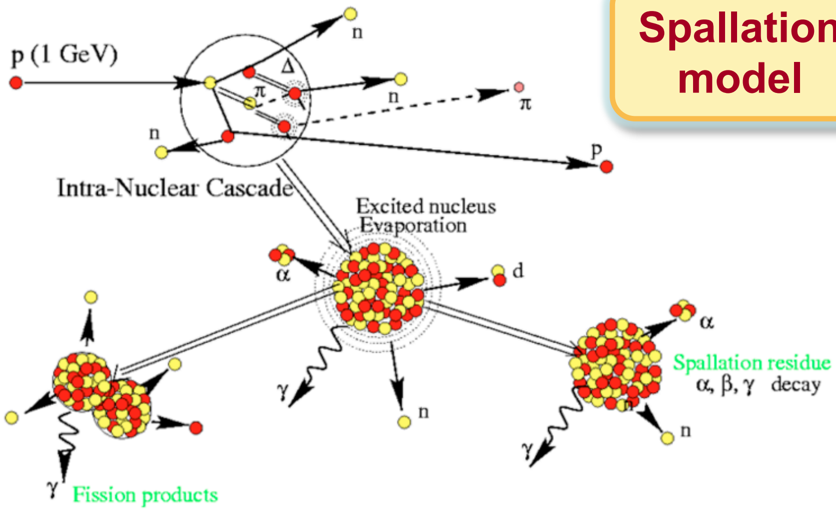
outline

- Introduction and Geometry
- Physics List
- MC simulation and resampling
- Results

Introduction



Spallation model

Neutron sources

In most applications it is important to know the **neutron flux**, and its **dependence on energy**, **spatial beam profile**, the **contamination of charged particles** and **gamma-rays** in the beam, and related background.

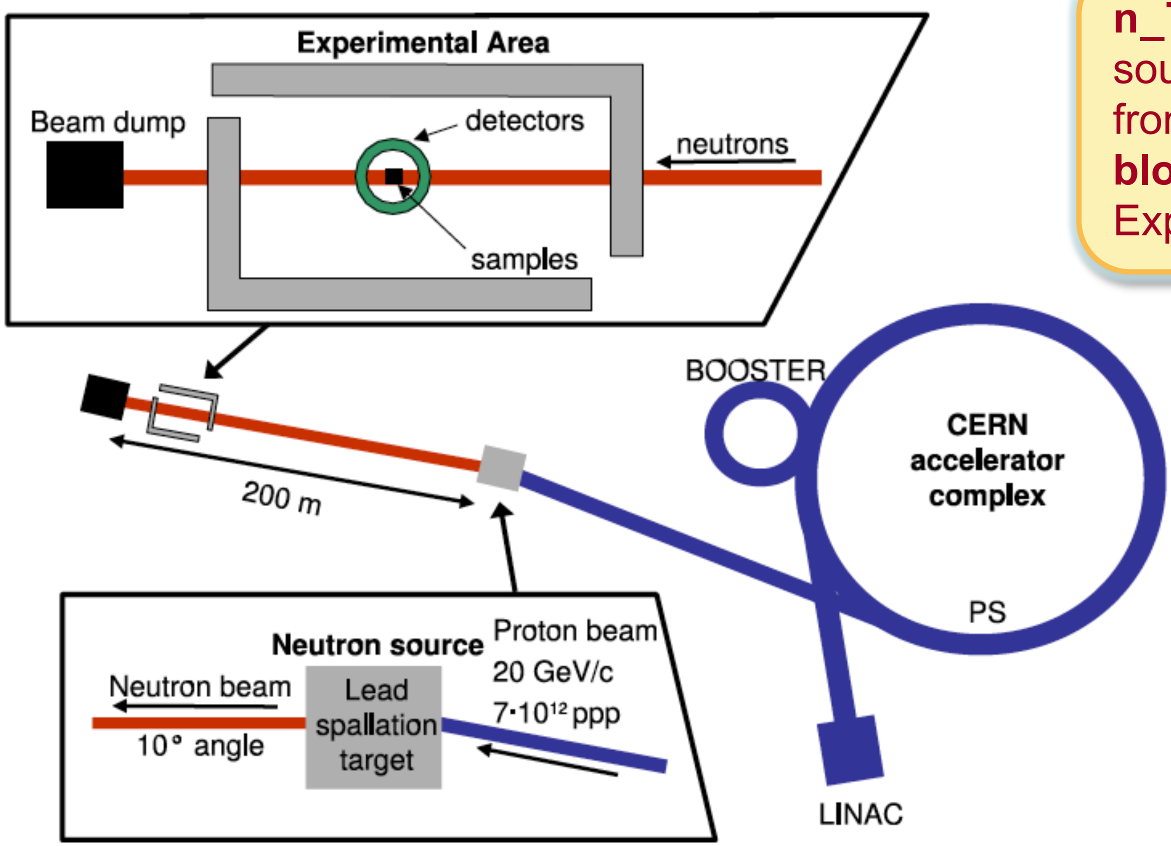
In **time-of-flight facilities** it is of crucial importance to know the so-called **response function** (the time distribution of neutrons emerging from the target with a given energy).

Neutron time-of-flight facilities

Facility	Ref.	Type	Particle Energy (MeV)	Target	Pulse width (ns)	Frequency (Hz)	Flight path length (m)
GELINA	[37]	e^-	80 - 140	U	1	40-800	10-400
KURRI (short pulse)	[38]	e^-	20 - 46	Ta	2, 5, 10, 22, 33, 47, 68, 100	1 - 300	10, 13, 24
KURRI (long pulse)		e^-	7 - 32	Ta	100 - 4000	1 - 100	10, 13, 24
nELBE	[35]	e^-	40	Pb	0.01	500000	4
ORELA	[34]	e^-	140	Ta	2 - 30	1 - 1000	10 - 200
POHANG	[39]	e^-	75	Ta	2000	12	11
RPI	[40]	e^-	60	Ta	7 - 5000	500	10 - 250
J-PARC/MLF - ANNRI	[41, 42]	p	3000	Hg	600	25	21, 28
LANSCE - MLNSC	[43, 44]	p	800	W	135	20	7 - 60
LANSCE - WNR	[43, 44]	p	800	W	0.2	13900	8 - [illegible]
n_TOF	[45]	p	20000	Pb	6	0.4	18[illegible]

Introduction

Istituto Nazionale di Fisica Nucleare



n_TOF is a neutron **spallation** source based on **20 GeV/c protons** from the CERN PS hitting a **Pb block** (~360 neutrons per proton). Experimental area at **200 m**.

Neutron flux	10^5 n/cm^2/pulse
Neutron energy	30 meV – 1 GeV
Energy resolution	DE/E ~ 10^{-4}
Repetition rate	~ 0.8 Hz

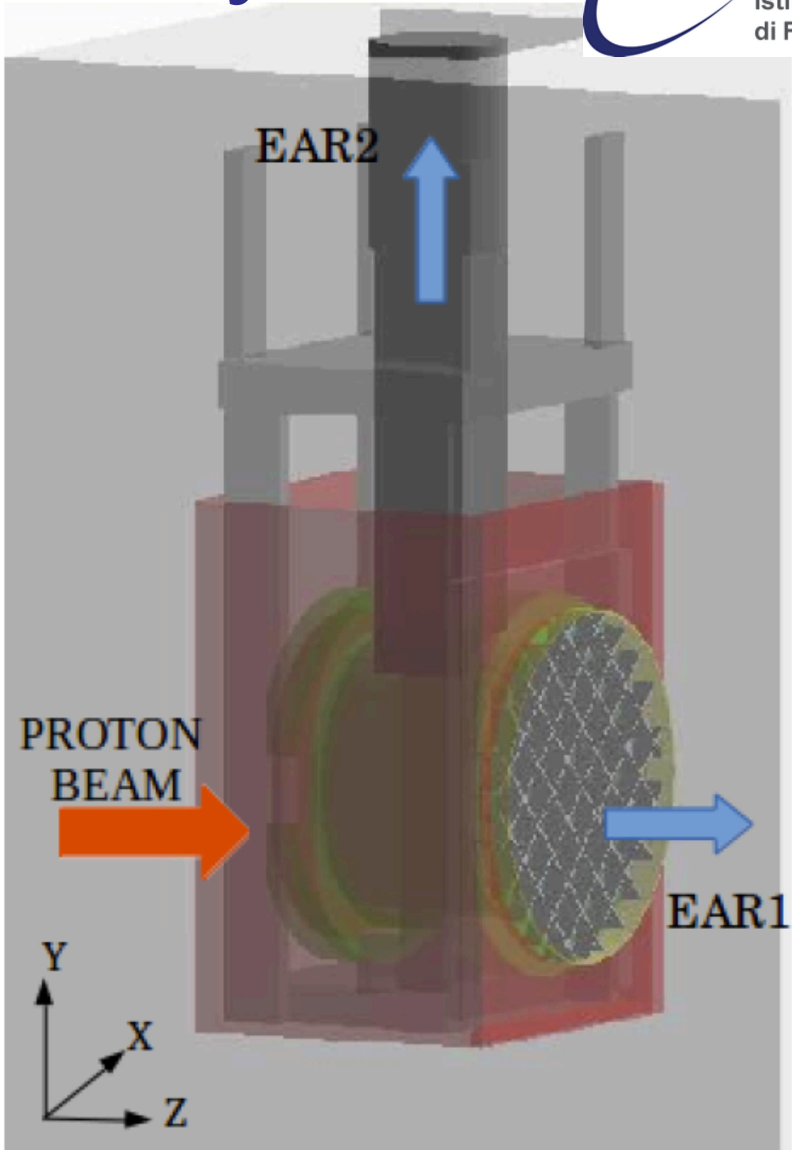
Geometry

n_TOF neutron-producing target

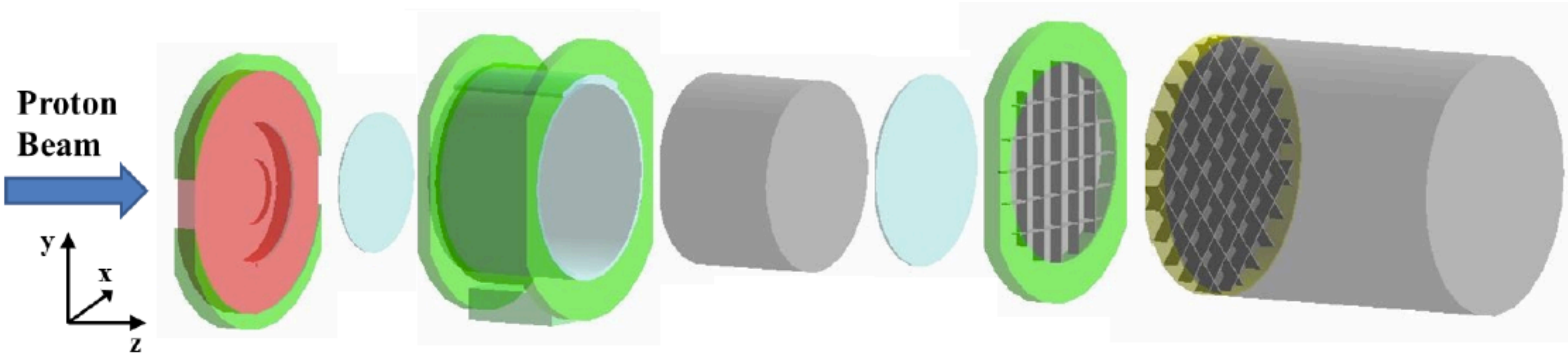
GEOMETRY: spallation target, coolant and moderator systems separated, the support structures and the concrete pit in which it is mounted.

2 SCORING PLANES: towards EAR1 and EAR2 (at the entrance of the beam pipe).

MODERATOR: borated water is made with 4.2% in weight of H_3BO_3, with a ^{10}B enrichment of 90%.



Geometry



FRONT part: the proton entrance window is a cylinder, made of an aluminum alloy, known as AW5083, made of 93.35% Al, 4.5% Mg and 7 other elements from Si to Zn. The main part, with outer and inner radius of 35 cm and 20 cm respectively, and a length of 10 cm, contains cooling water.

TARGET part: spallation volume, made of Pb, surrounded by a layer of water, all in serted in the aluminum alloy container. The Pb block is a cylinder 30 cm in radius and 40 cm in length. It is made of a lead alloy with 99.974% Pb and traces of 37 chemical elements ranging from Li to U.

END part: 4 cm thick layer of borated water (moderator for EAR1)which contains 4.2 weight% of H_3BO_3 and enrichment of 95%, enclosed between two Al sheets 3 mm thickness, reinforced by an internal grid.

Physics List

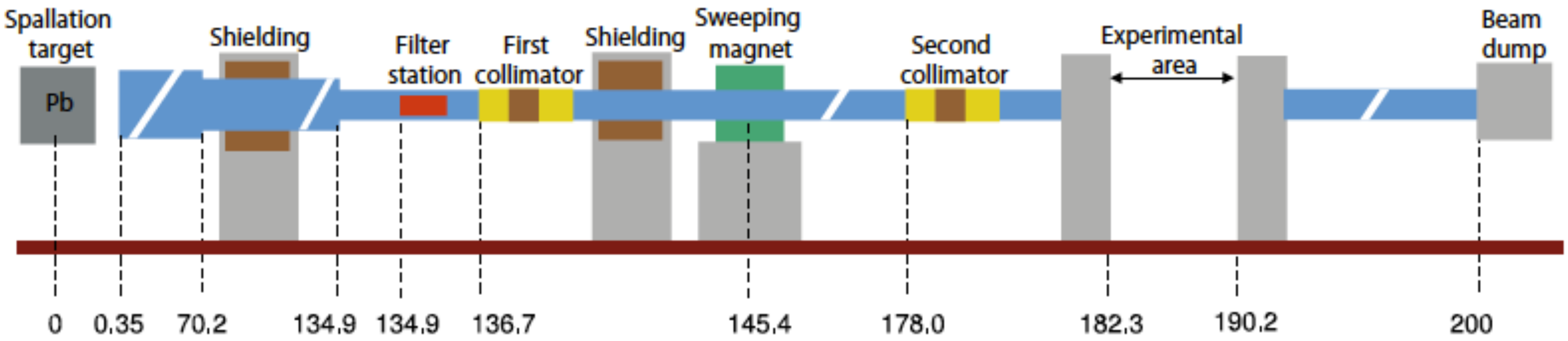
Geant4 10.01 version (December 2014): **FTFP_INCLXX_HP** Physics List:

- **Inelastic interaction of high-energy protons:** the Fritiof model is used in Geant4 **FTFP** for simulation of the following interactions: hadron-nucleus at $P_{lab} > 3 - 4$ GeV/c, nucleus-nucleus at $P_{lab} > 2 - 3$ GeV/c/nucleon, antibaryon-nucleus at all energies, and antinucleus-nucleus.
- **Intra-nuclear cascade:** the Liège Intranuclear Cascade model **INCL++** is suitable for the simulation of spallation reactions or light-ion-induced reactions, for reactions induced by nucleons with $P_{lab} < 3$ GeV/c.
- **De-excitation:** we have tried both the default **G4ExcitationHandler** model of INCL++ and **ABLA** model that was recognized as one of the best de-excitation model by the IAEA Benchmark of Spallation Models. We have also tried different Physics List (***QGSP, BERT, BIC*** …)

HP: the NeutronHP model (E_n<20 MeV) simulates all reactions induced by neutrons using evaluated data libraries (G4NDL).

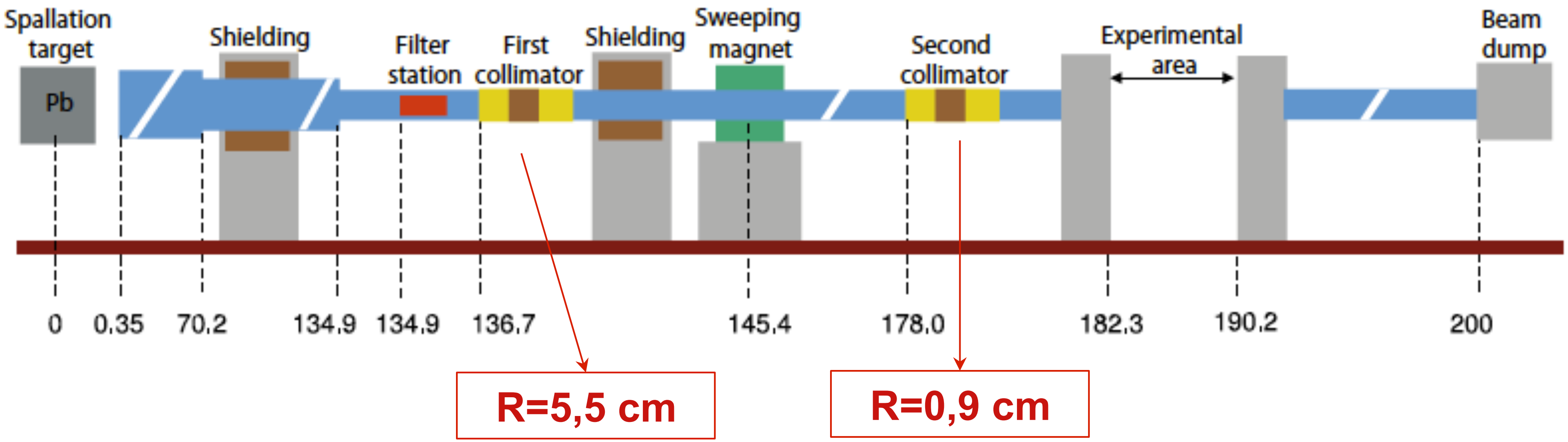
MC and resampling

n_TOF beam line



MC and resampling

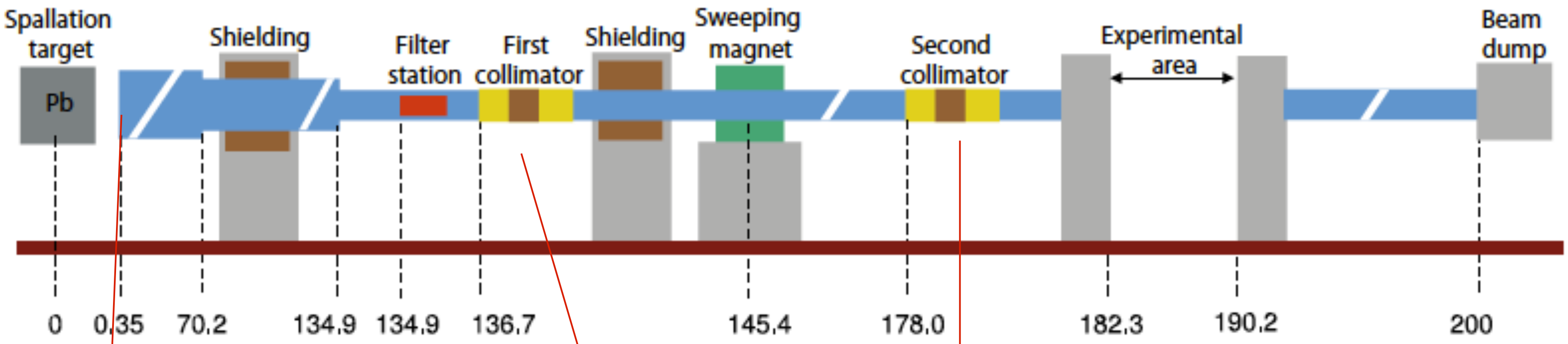
n_TOF beam line



Ω ~10^{-8} sr
5×10^{6} protons → 1 neutron

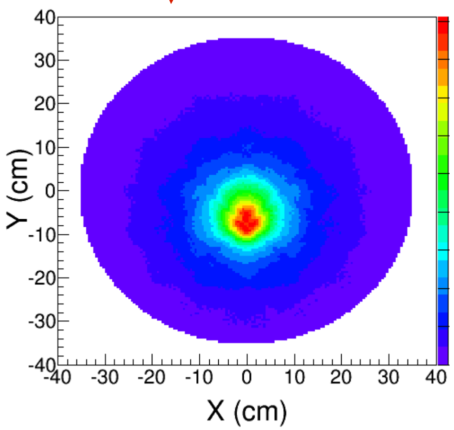
MC and resampling

n_TOF beam line



R=5,5 cm

R=0,9 cm

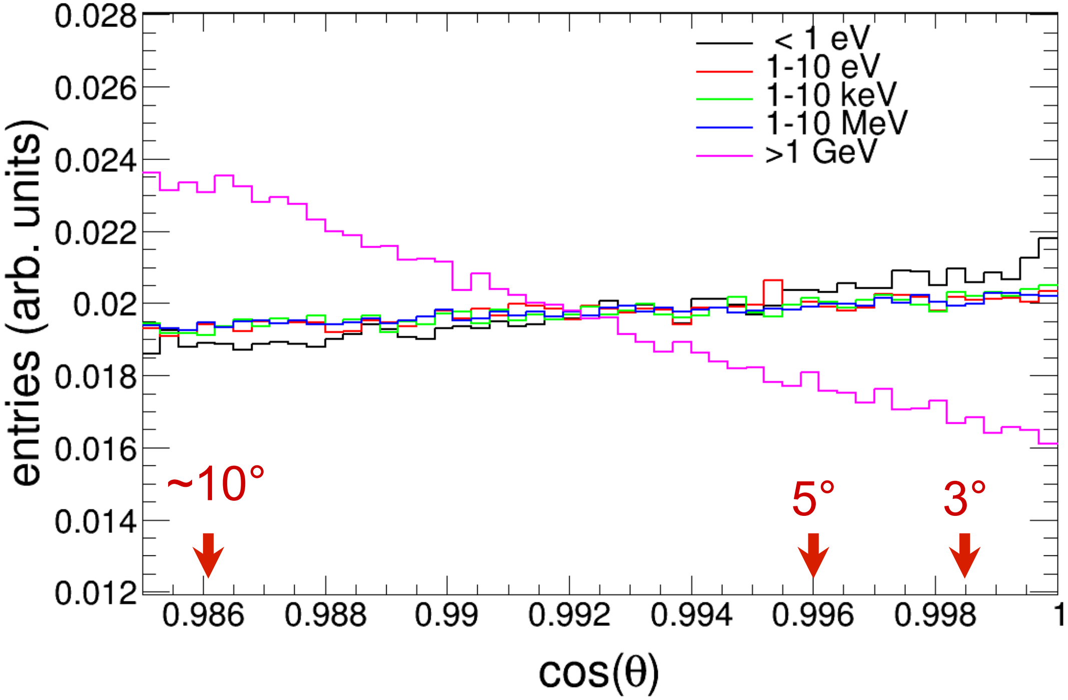


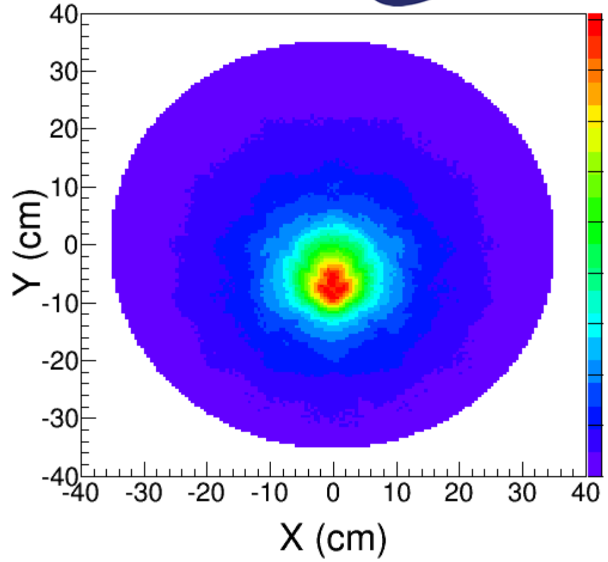
Ω ~10^{-8} sr
5×10^6 protons → 1 neutron

1/2 week CPUs = 10^6 protons !!!

MC and resampling

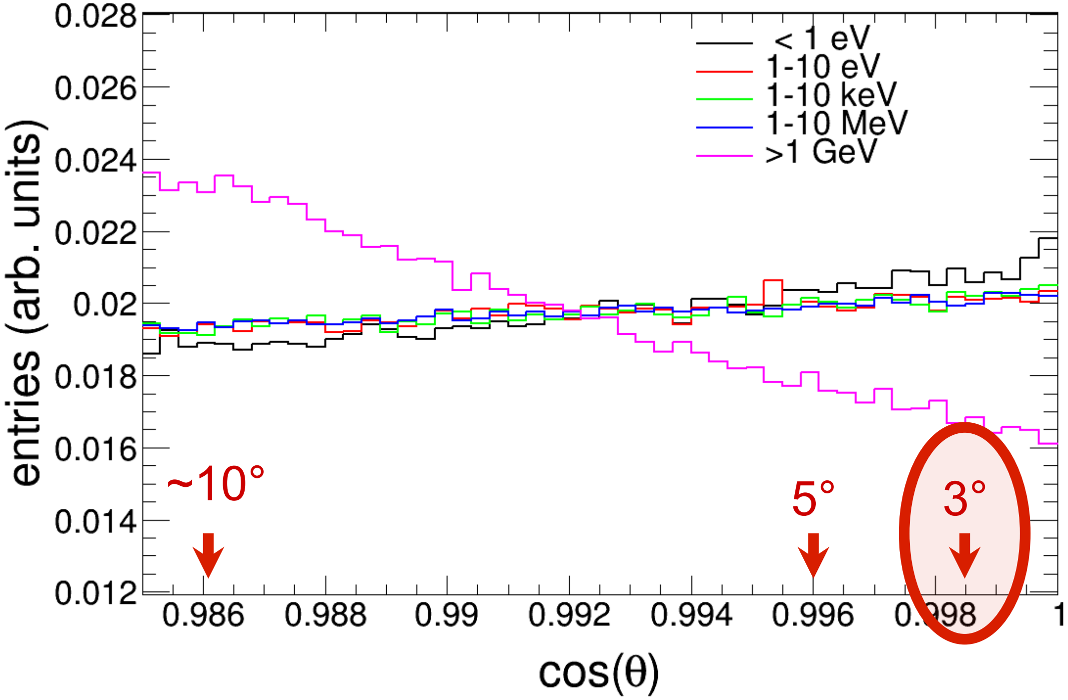
Scoring plane at target,
events with $\theta < 10°$ and $3°$, propagated to EAR1

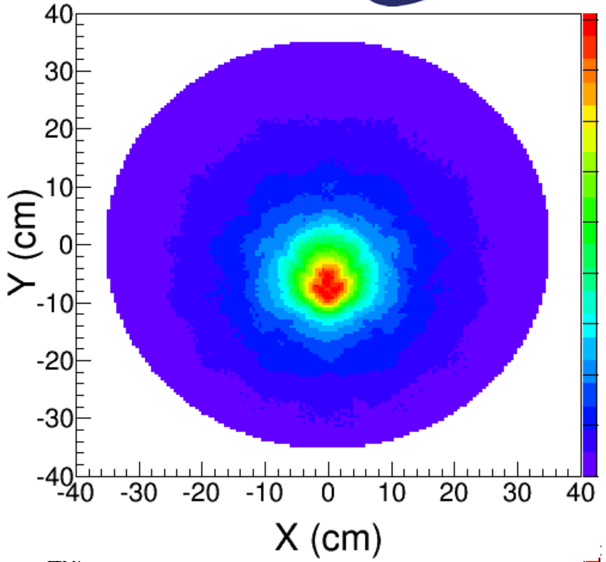


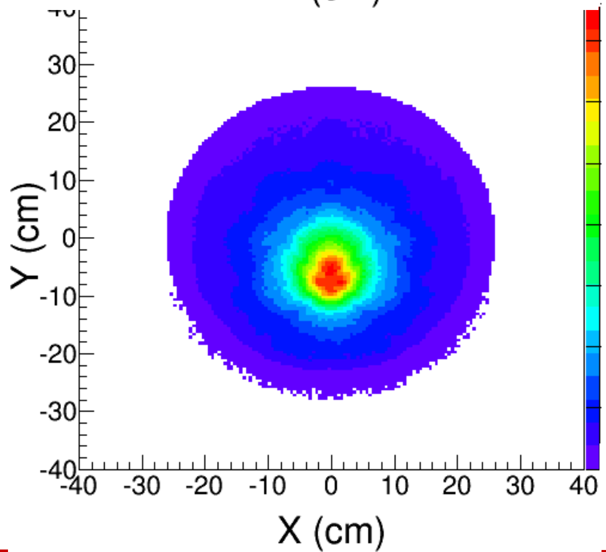


MC and resampling

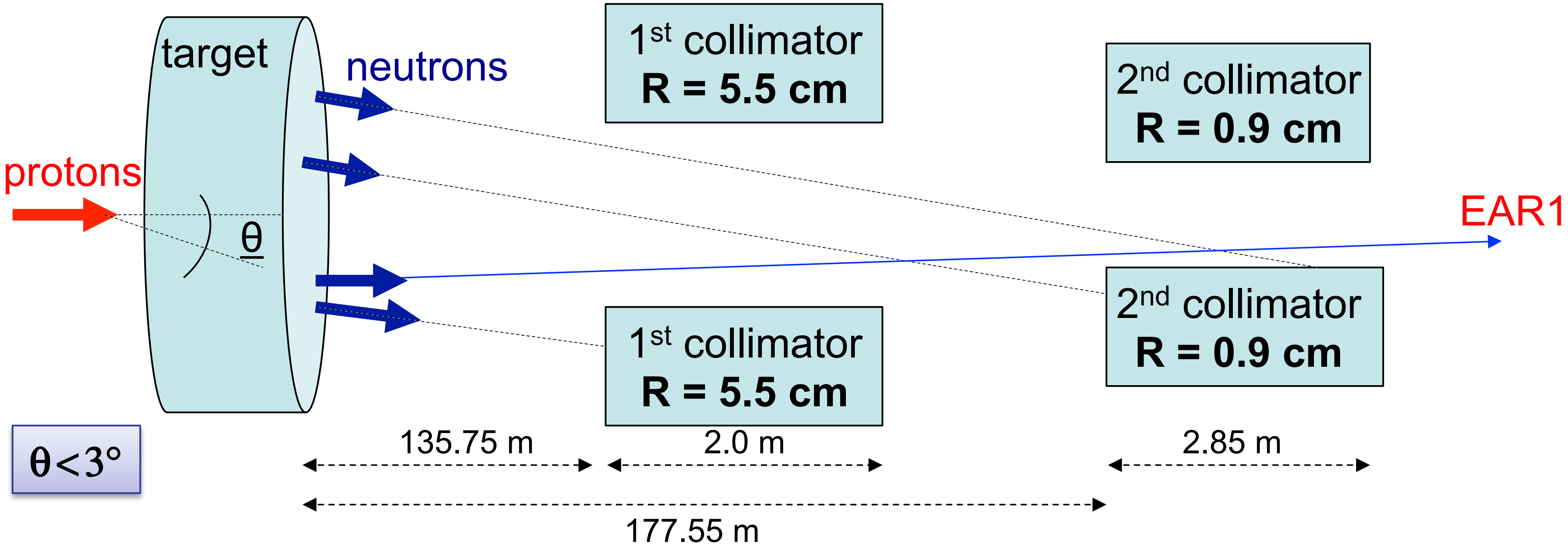
Scoring plane at target
events with $\theta < 10°$ and 3°, propagated to EAR1



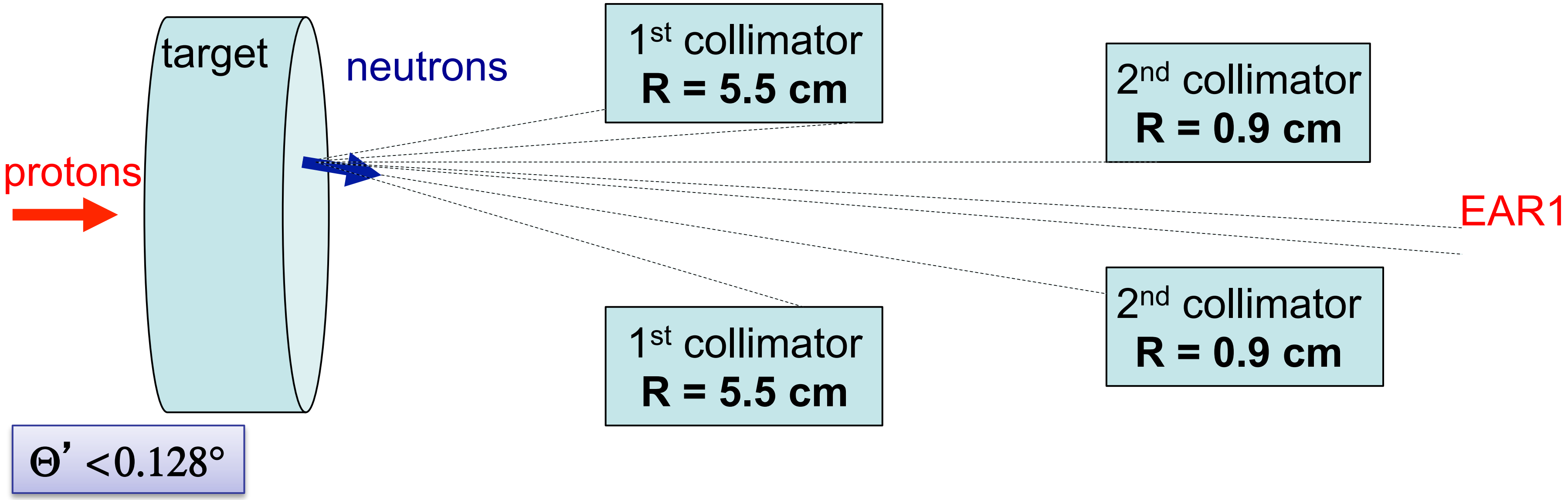


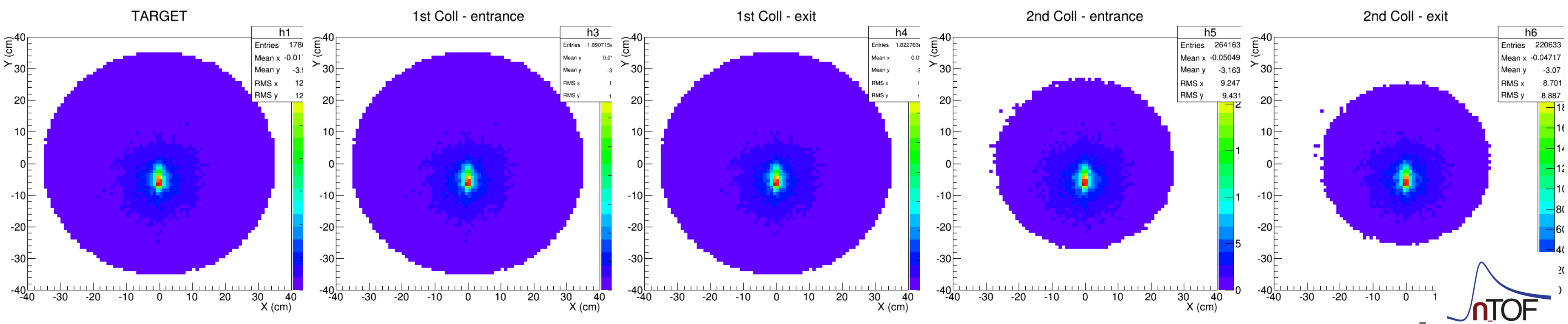


MC and resampling

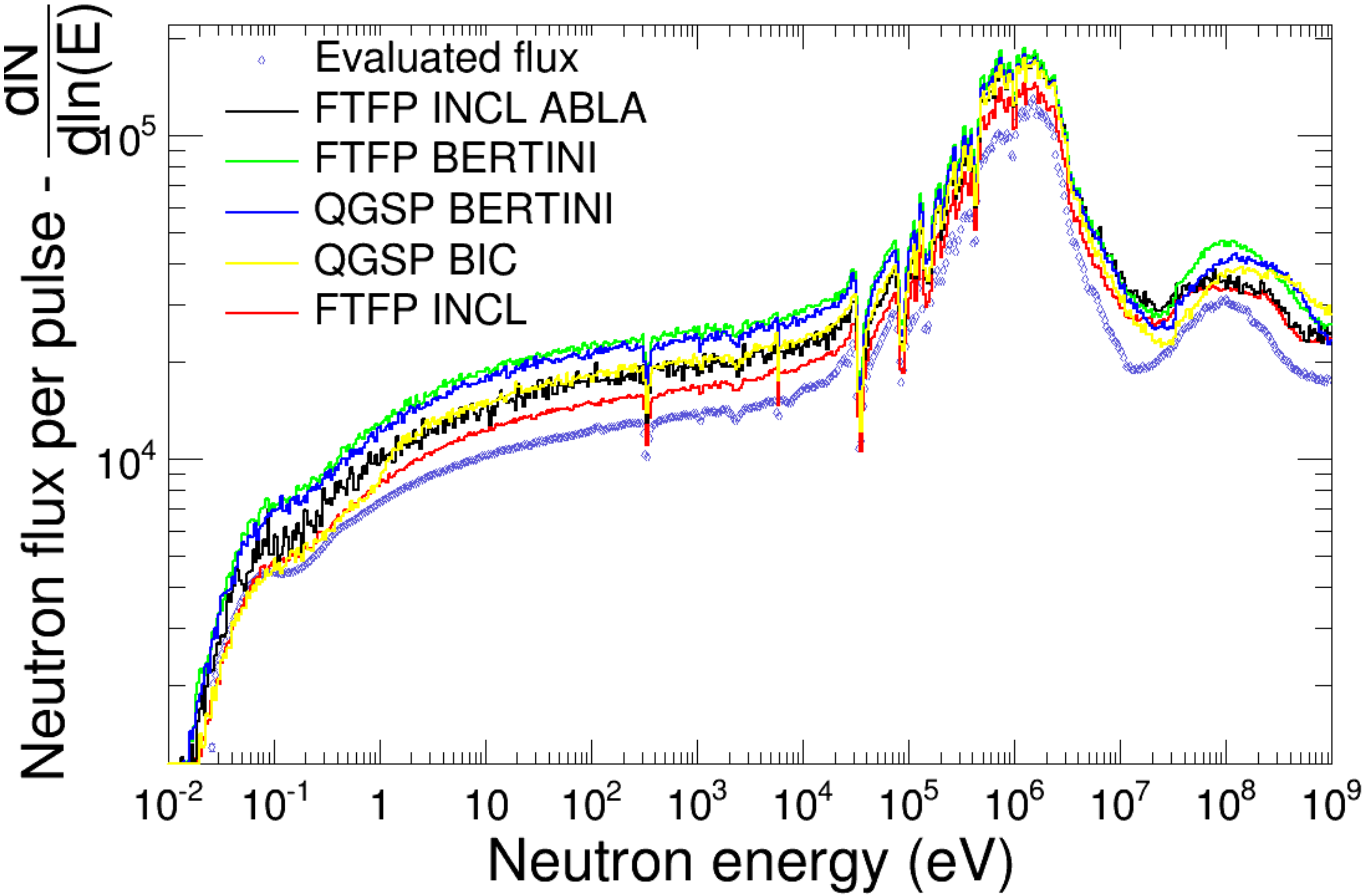


MC and resampling



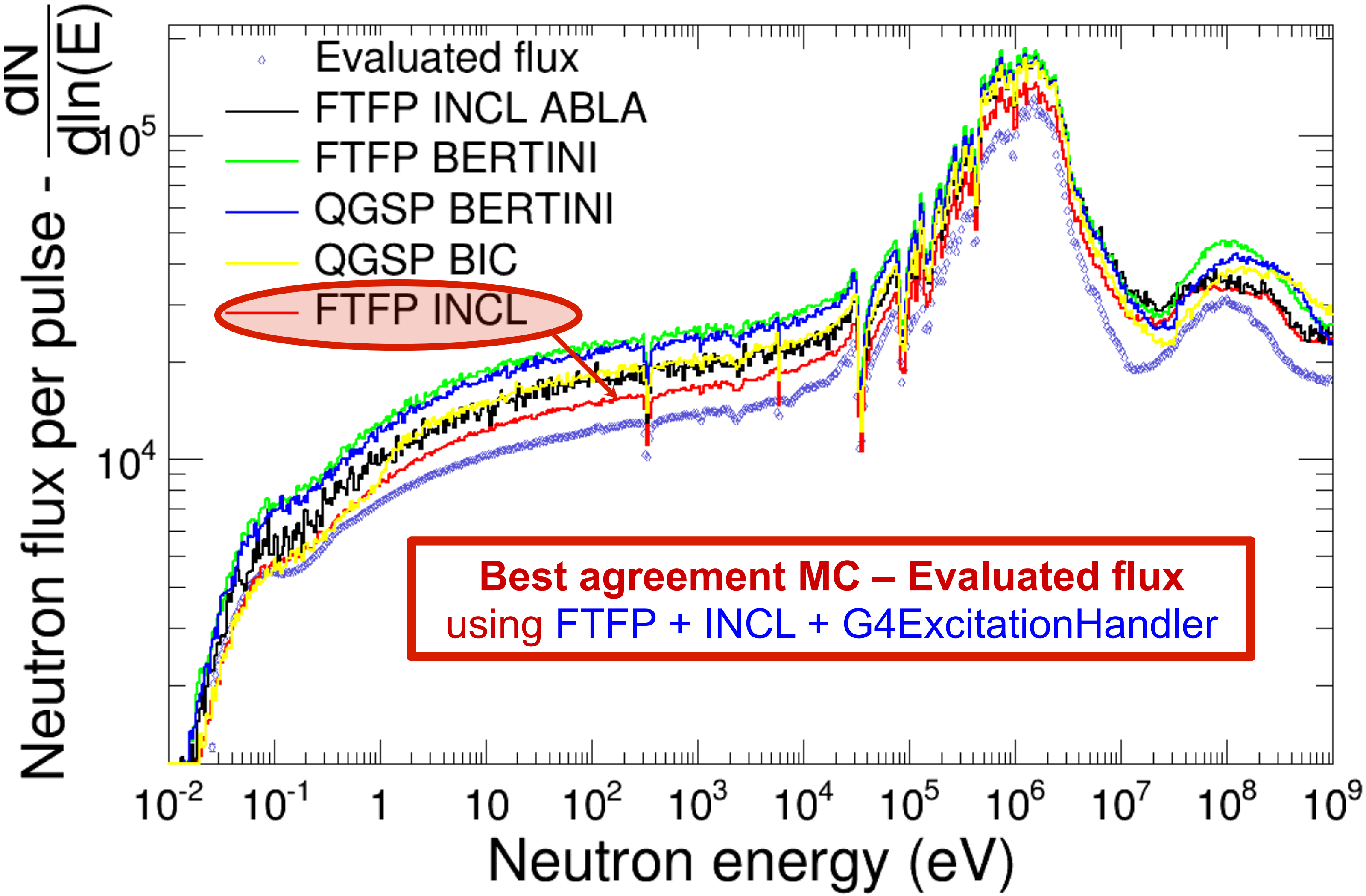


Results



Evaluated flux
FTFP INCL ABLA
FTFP BERTINI
QGSP BERTINI
QGSP BIC
FTFP INCL
Neutron flux per pulse - $\frac{dN}{dln(E)}$
10^5
10^4
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Neutron energy (eV)

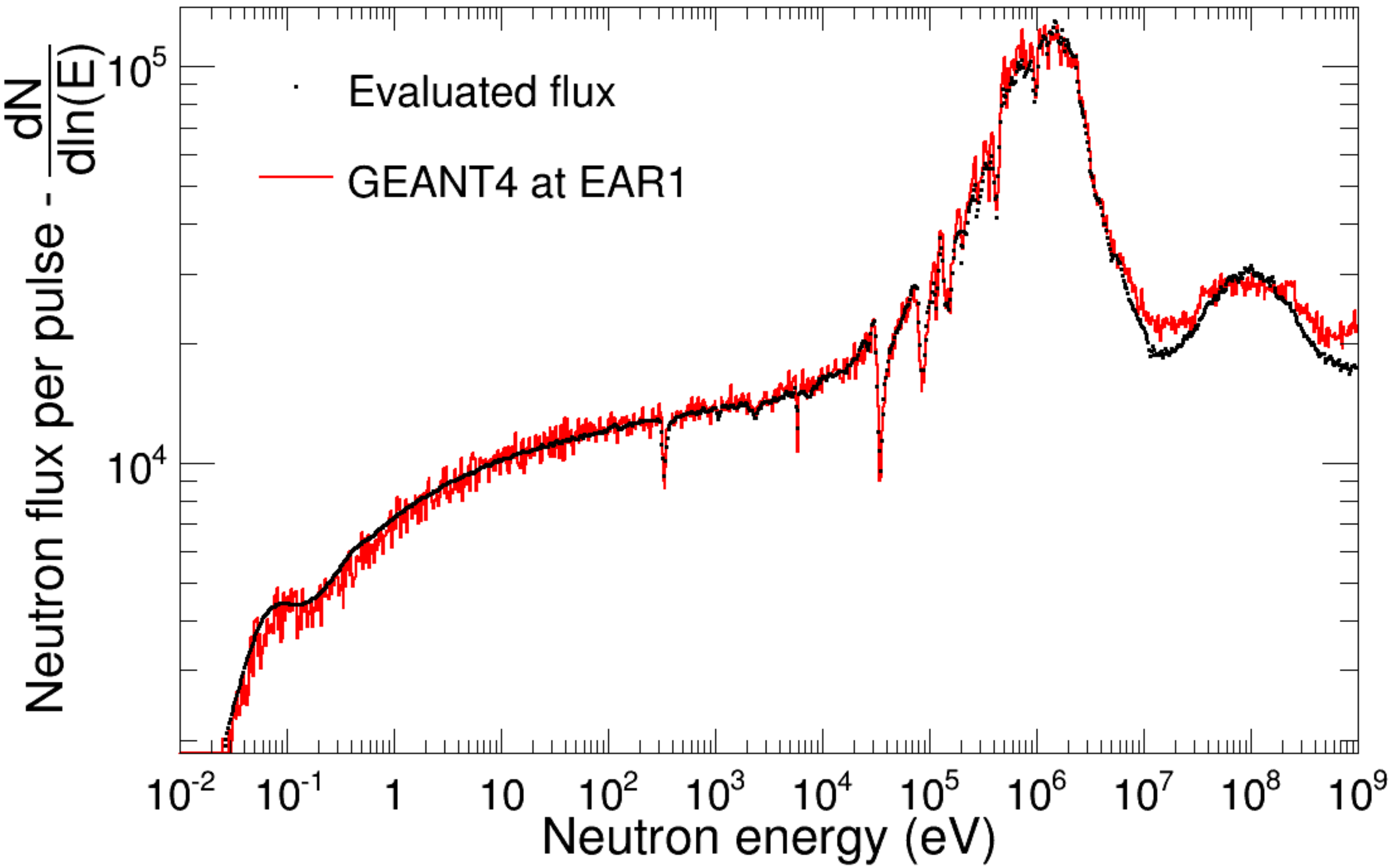
Results



Best agreement MC – Evaluated flux
using FTFP + INCL + G4ExcitationHandler

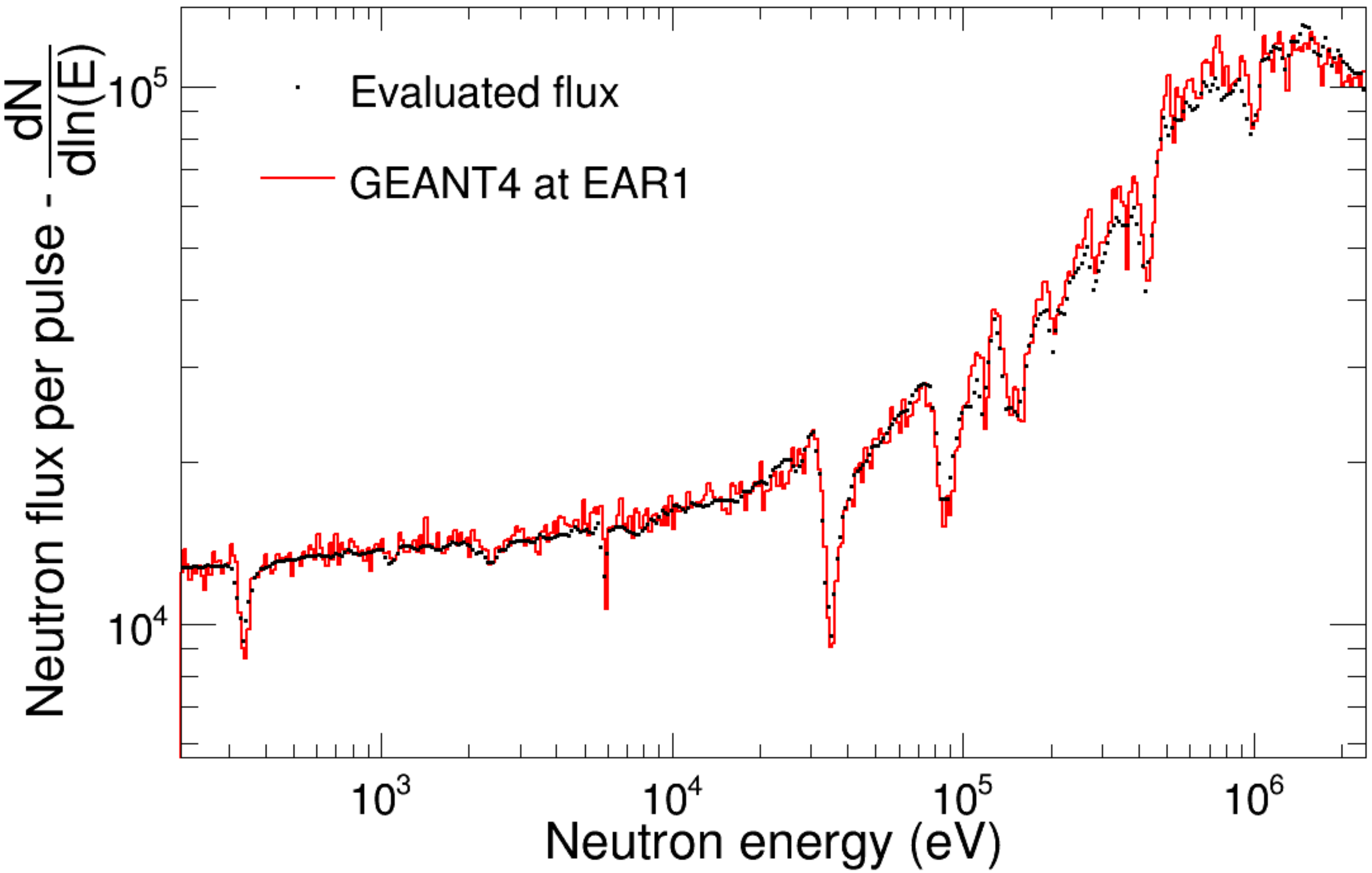
Results

FLUX after Resampling - Simulation arbitrarily scaled ~20%



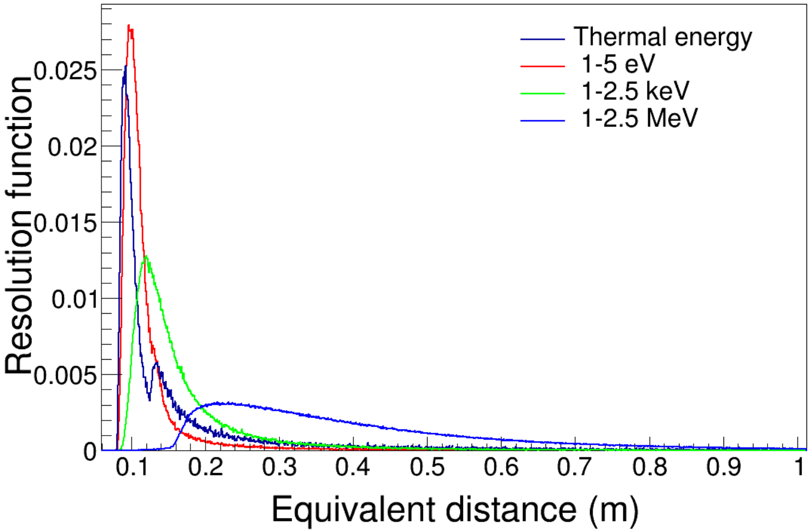
Results

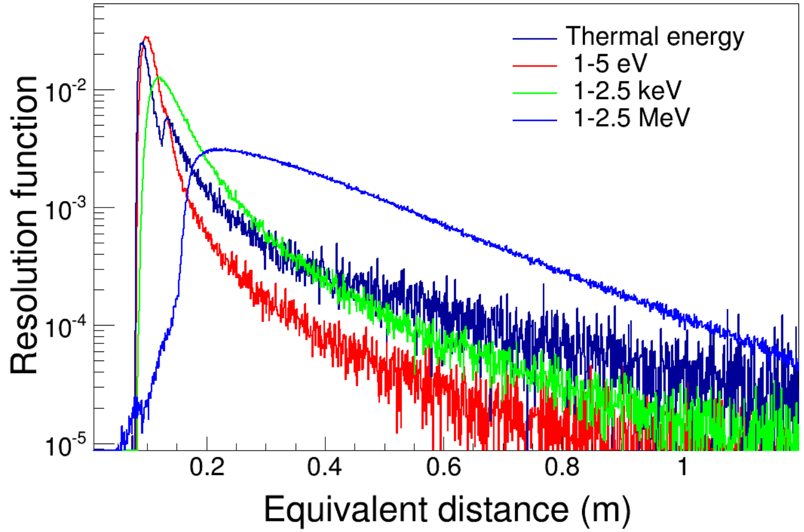
FLUX after Resampling - Simulation arbitrarily scaled ~20%



Results

Resolution function, impact on resonances



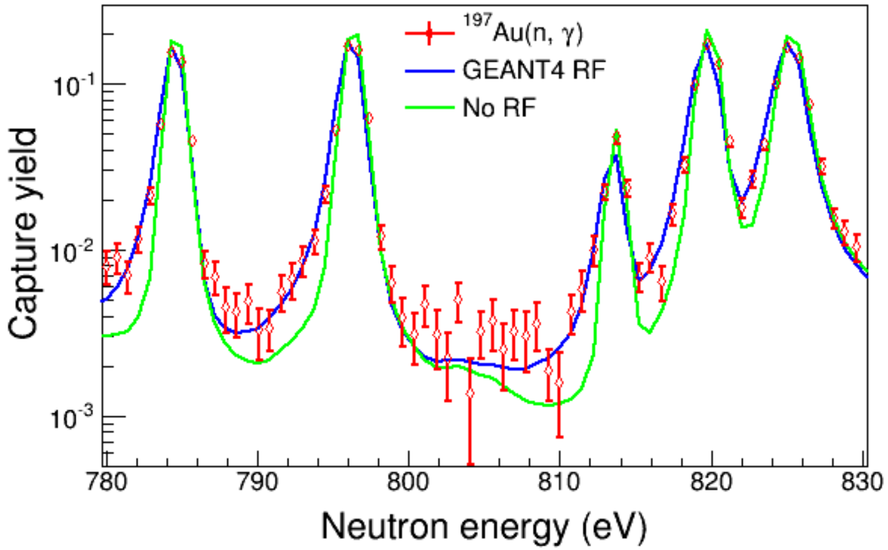


$$\lambda = vt_{\mathrm{mod}}$$

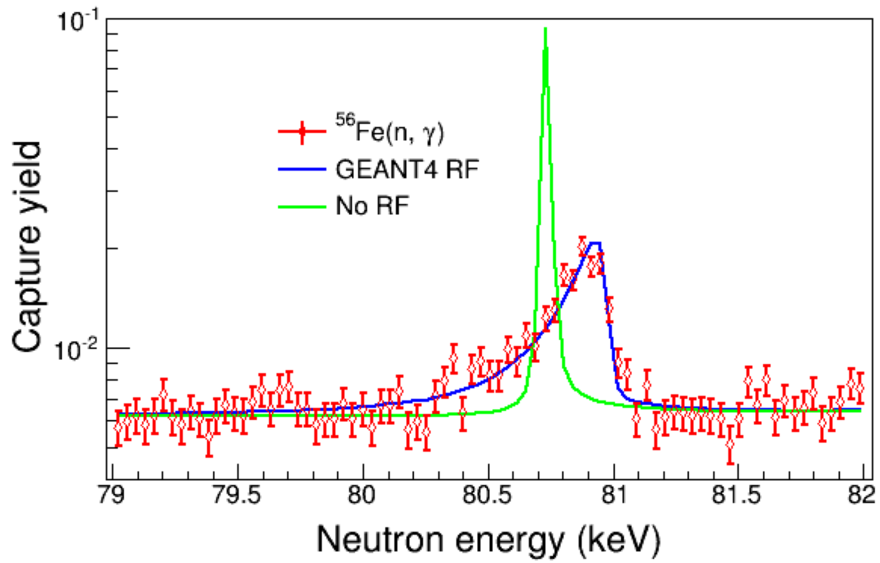
- λ → **Equivalent distance**
- v → **Velocity at the scoring plane**
- t_{mod} → **Time spent by the neutron inside the target assembly**

Results

Resolution function, impact on resonances



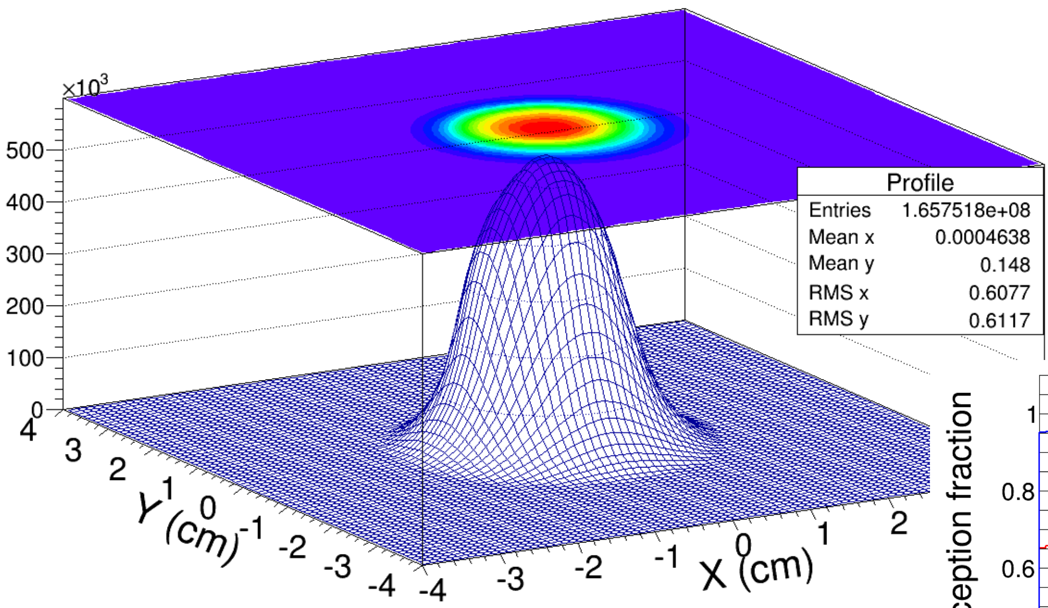
The stochastic process of **moderation** inside the neutron-producing target causes a **broadening of** the **energy** distribution of neutrons reaching the experimental area at a given TOF.



Well-known neutron resonances of ^{197}Au and ^{56}Fe

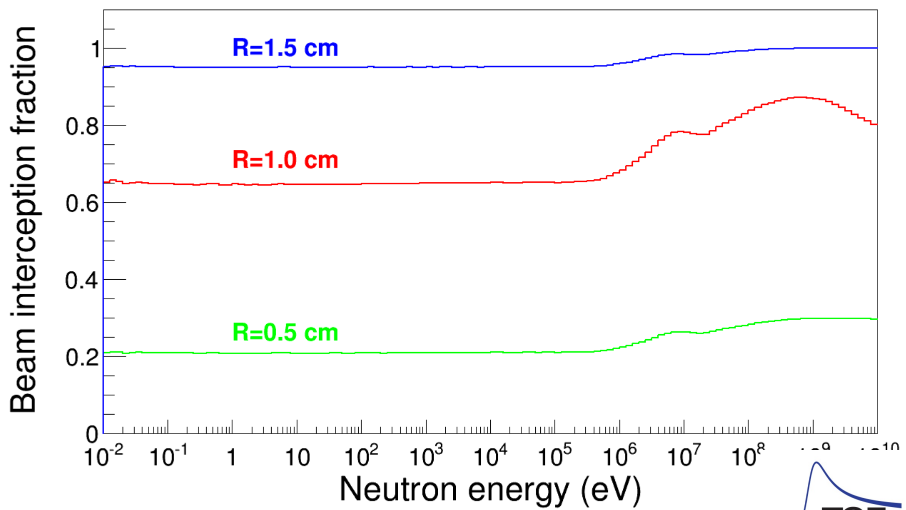
Results

Beam Profile

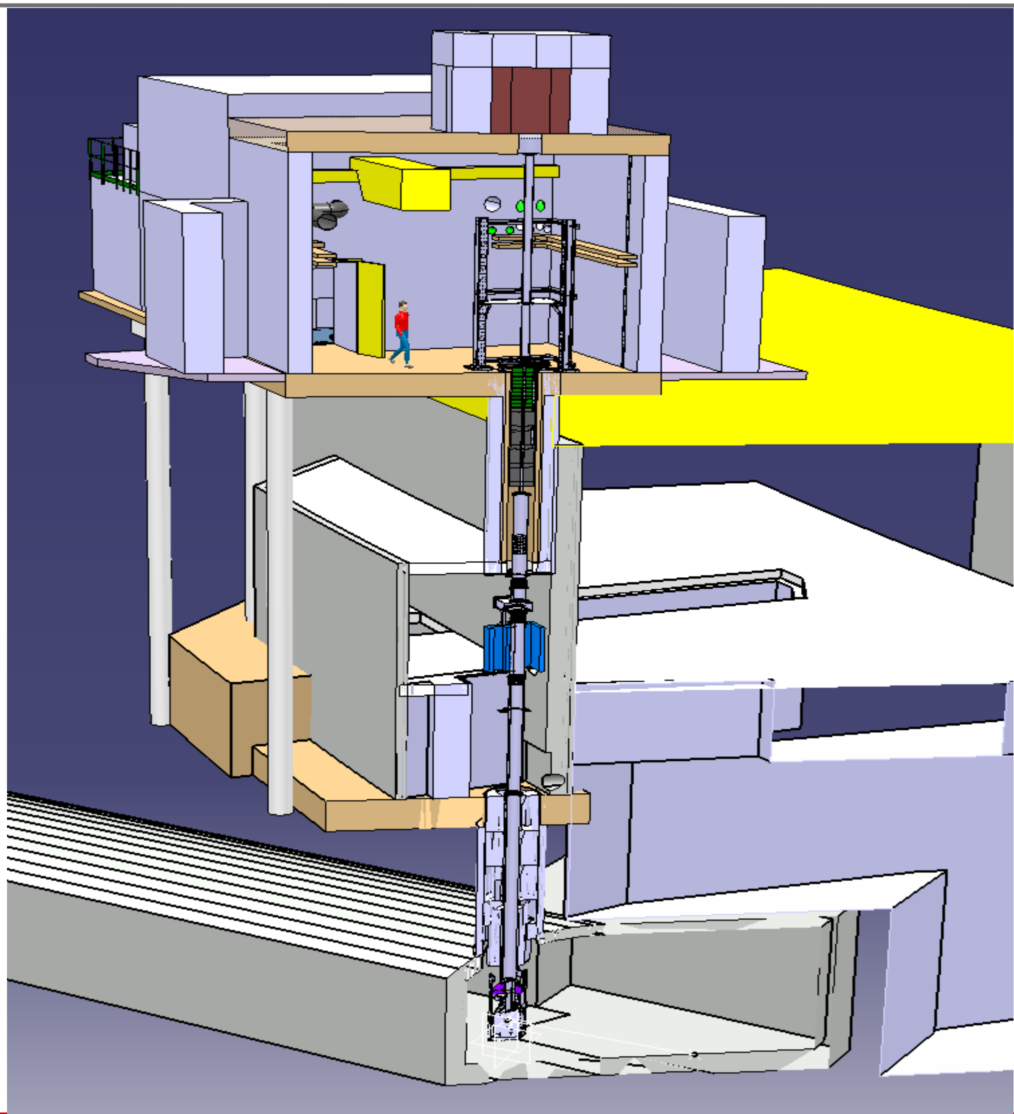


at **185.2 m**
Gaussian beam profile
RMS ~ 6 mm

Radius (cm)	BIF at 185.2 m (flat region)	BIF at 185.2 m (E_n=1 MeV)
0.5	0.21	0.22
1.0	0.65	0.68
1.5	0.95	0.96

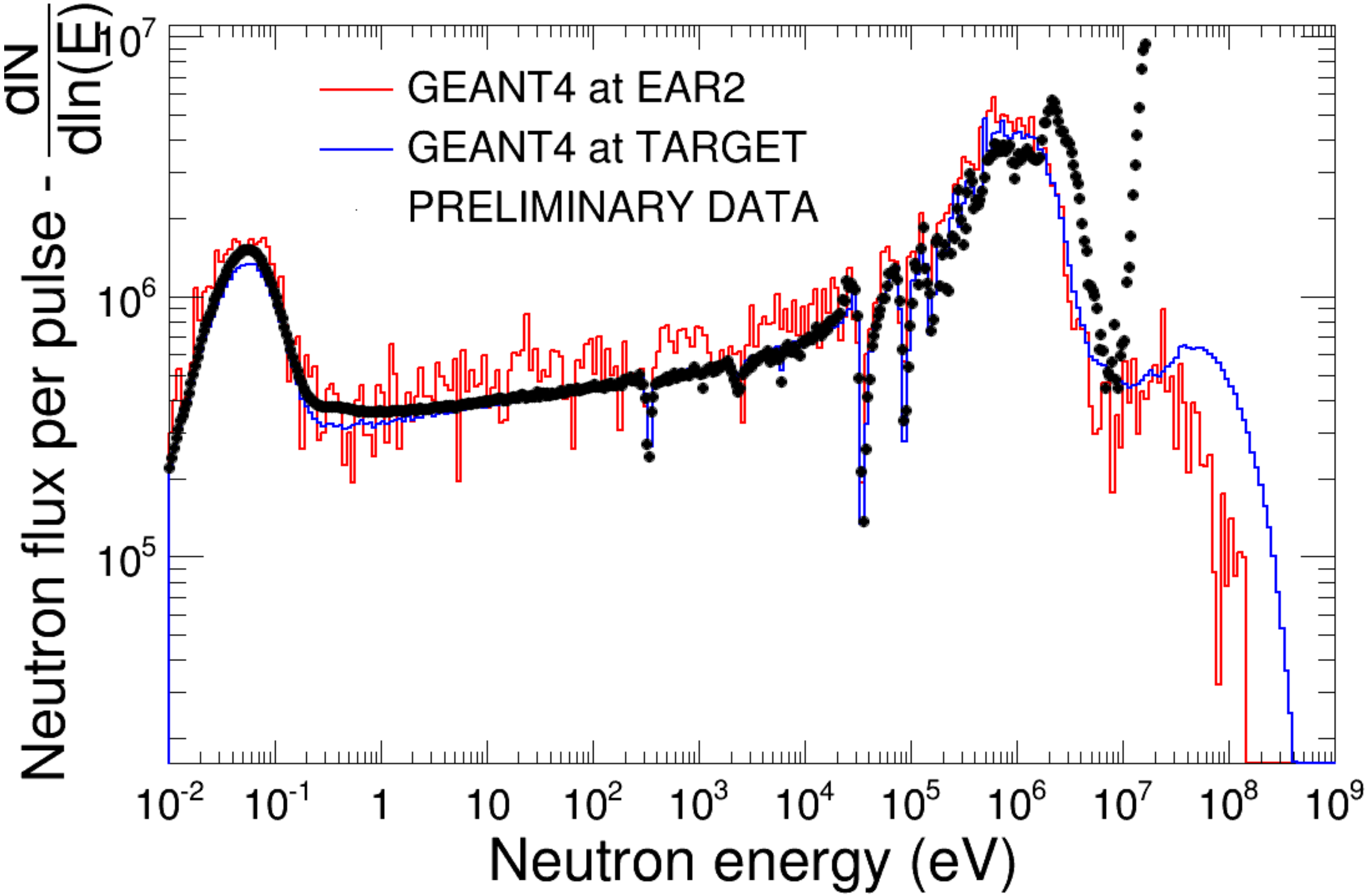


Results – EAR2



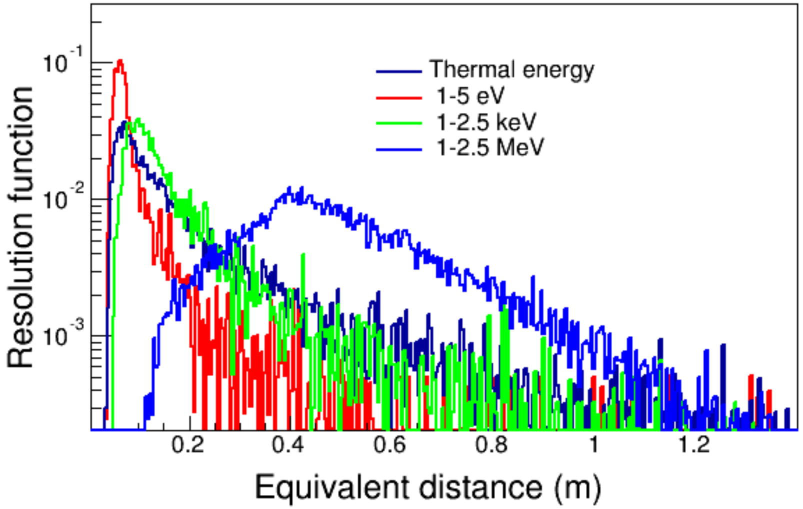
Results – EAR2

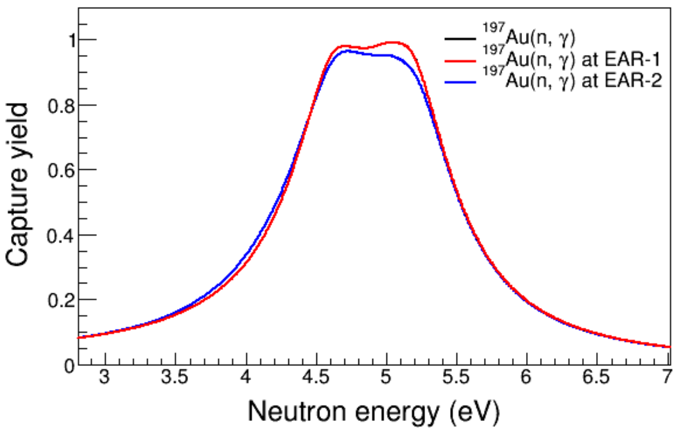
FLUX after Resampling - Simulation arbitrarily scaled ~20%

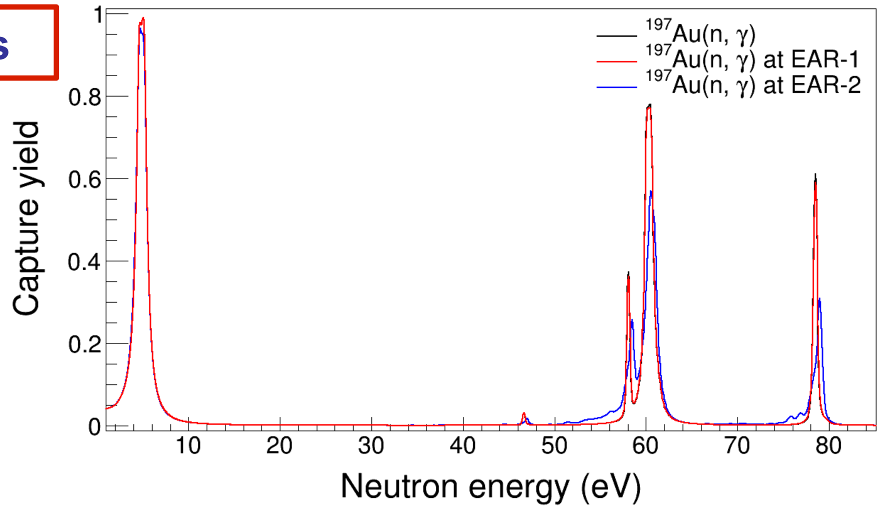


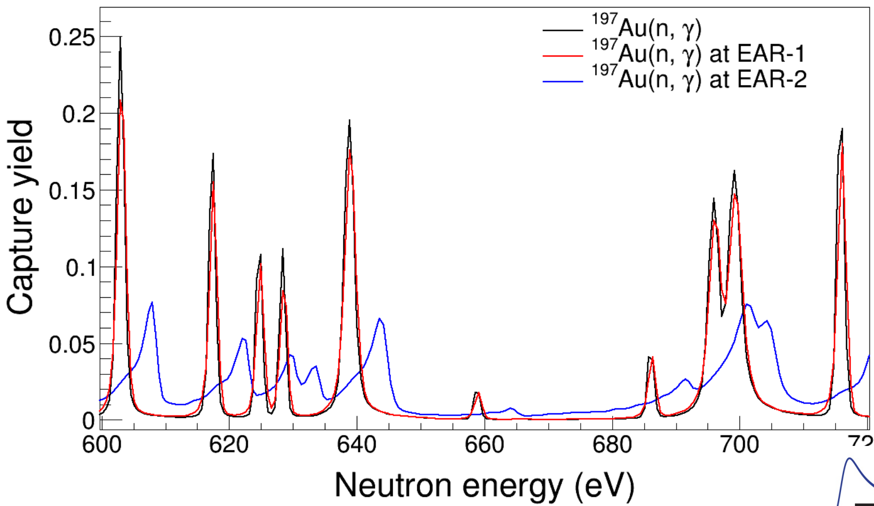
Results – EAR2

Resolution function, impact on resonances



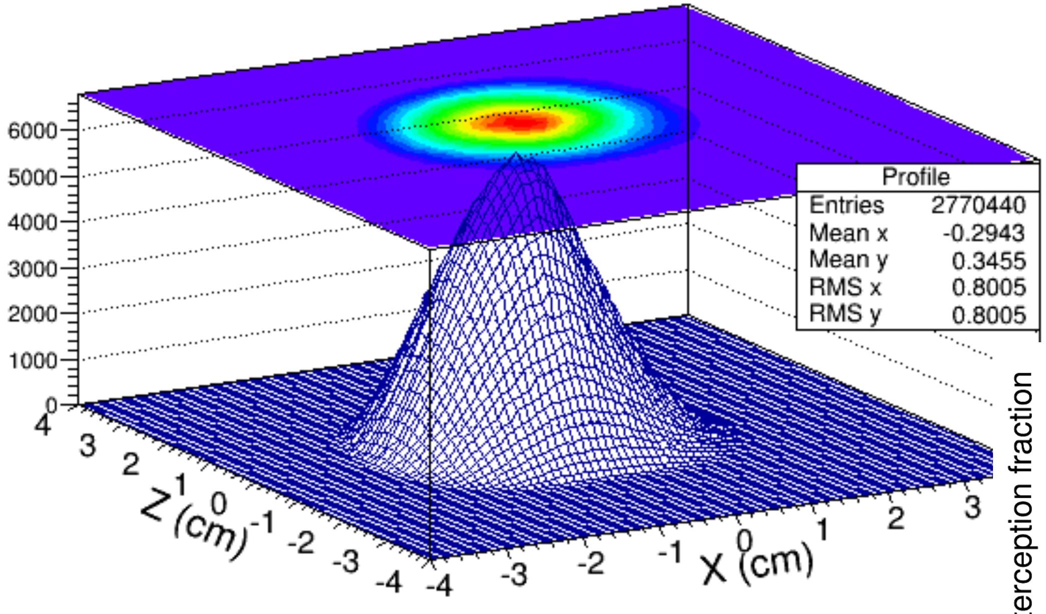






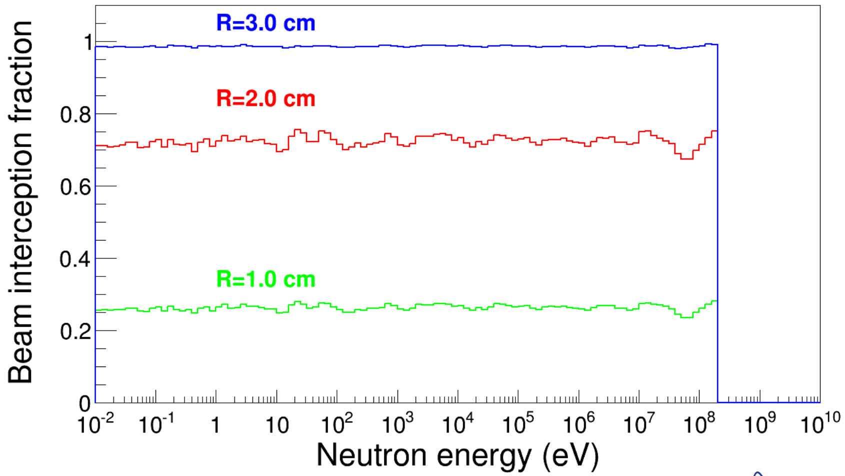
Results – EAR2

Beam Profile



Almost independent of energy

at **19.2 m**
~ Gaussian beam profile
RMS ~ 1.2 cm



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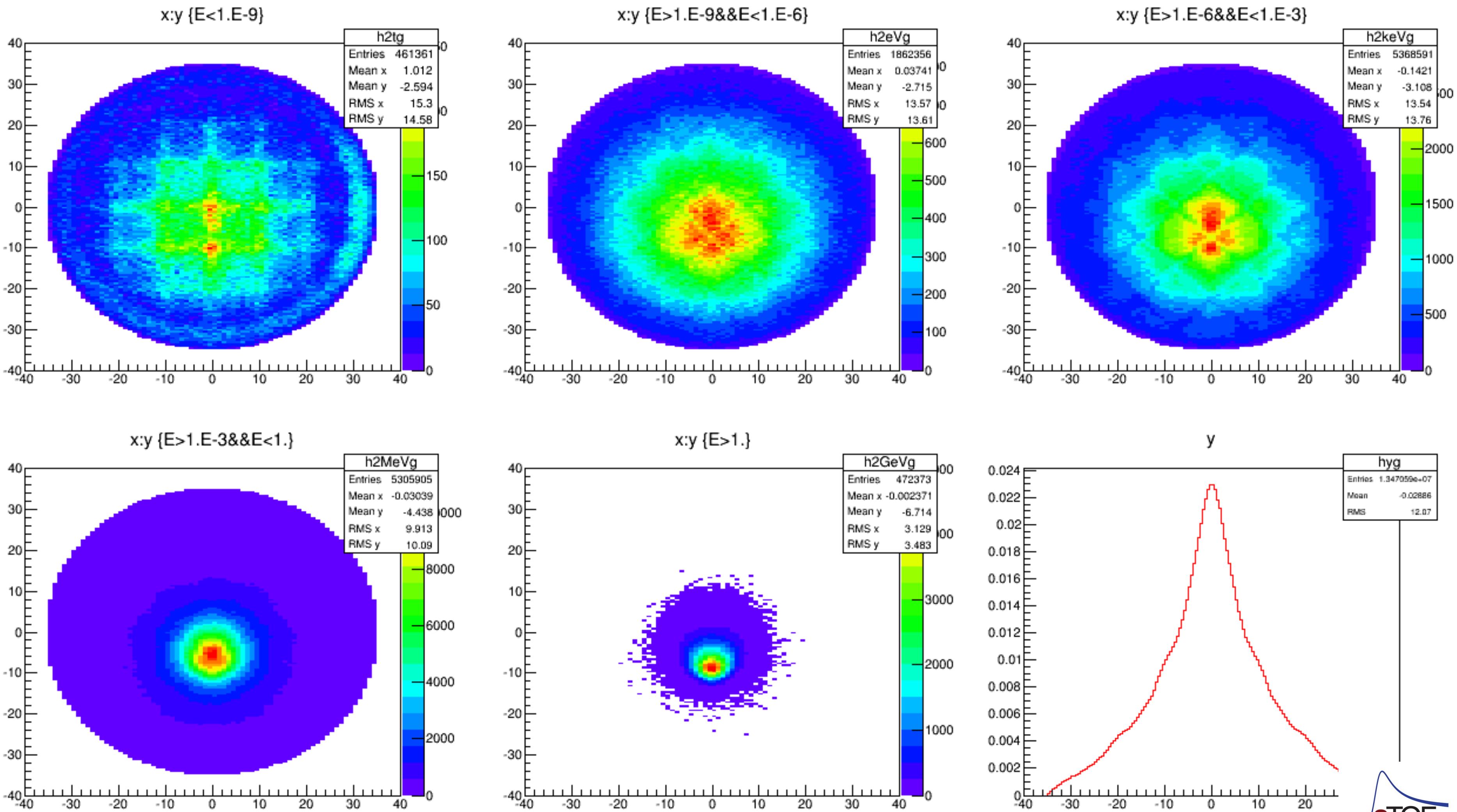
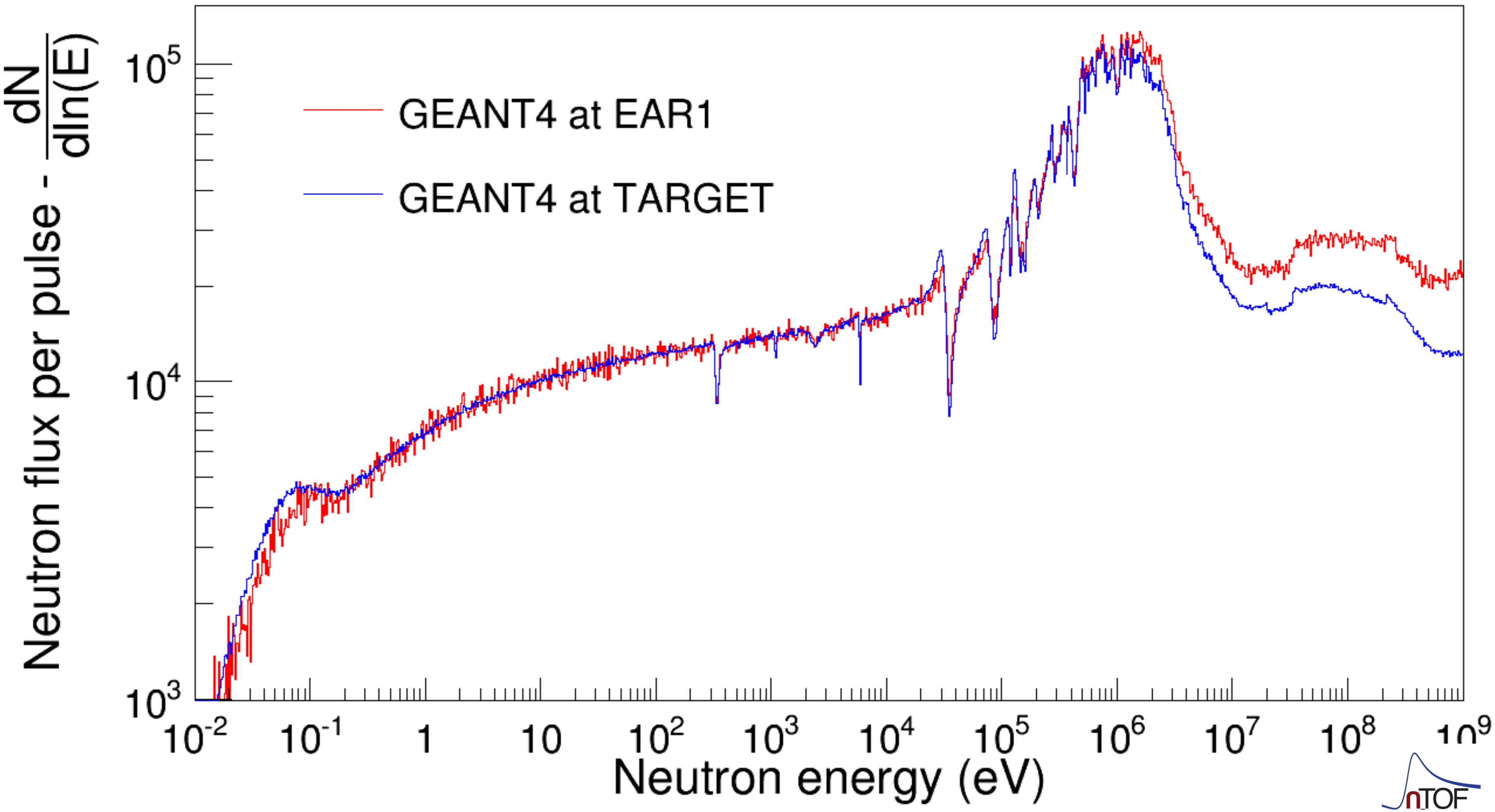
Resampling

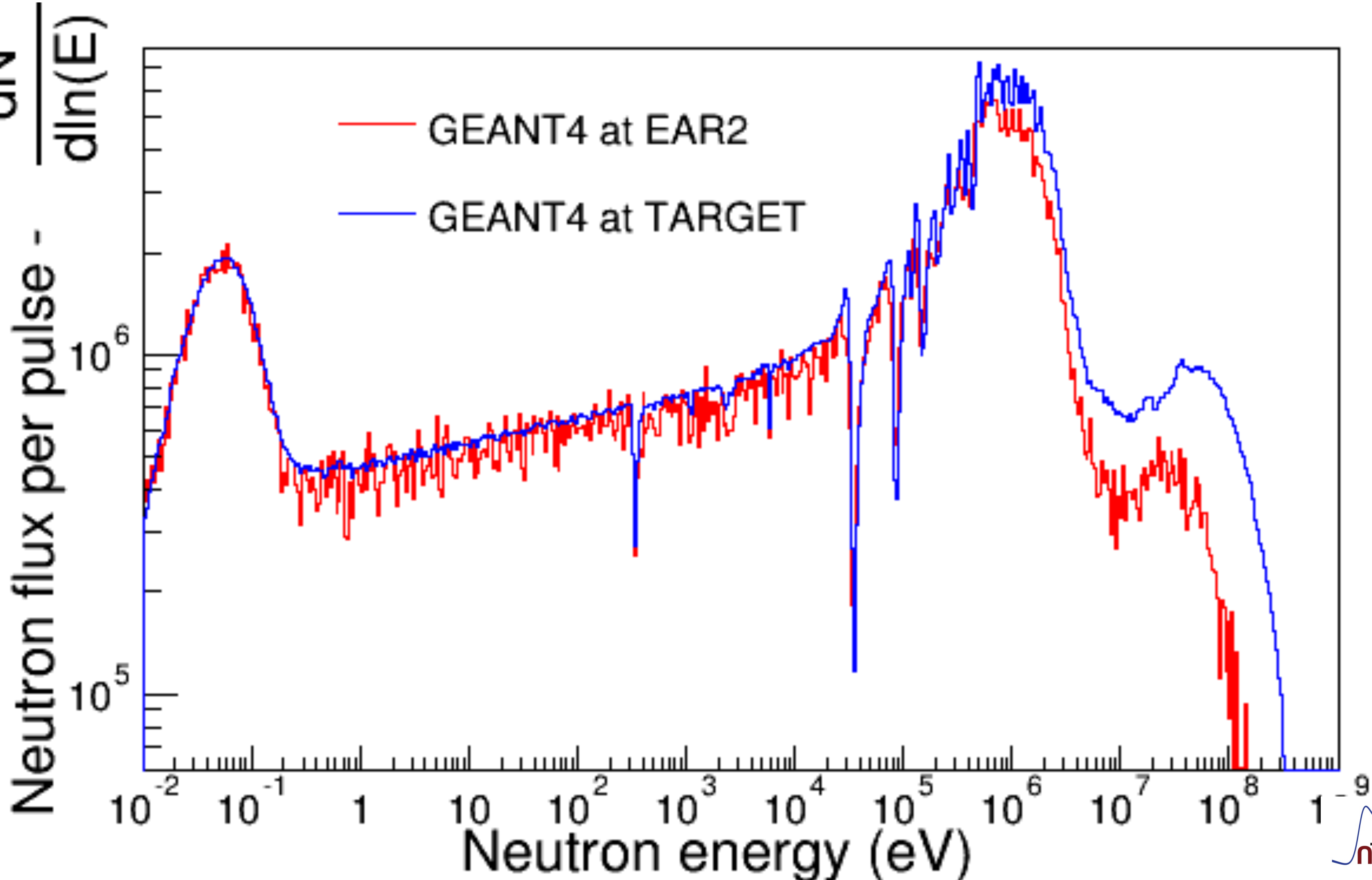


x:y {E<1.E-9}
h2tg
Entries 461361
Mean x 1.012
Mean y -2.594
RMS x 15.3
RMS y 14.58
x:y {E>1.E-9&&E<1.E-6}
h2eVg
Entries 1862356
Mean x 0.03741
Mean y -2.715
RMS x 13.57
RMS y 13.61
x:y {E>1.E-6&&E<1.E-3}
h2keVg
Entries 5368591
Mean x -0.1421
Mean y -3.108
RMS x 13.54
RMS y 13.76
x:y {E>1.E-3&&E<1.}
h2MeVg
Entries 5305905
Mean x -0.03039
Mean y -4.438
RMS x 9.913
RMS y 10.09
x:y {E>1.}
h2GeVg
Entries 472373
Mean x -0.002371
Mean y -6.714
RMS x 3.129
RMS y 3.483
y
hyg
Entries 1.347059e+07
Mean -0.02886
RMS 12.07

Resampling

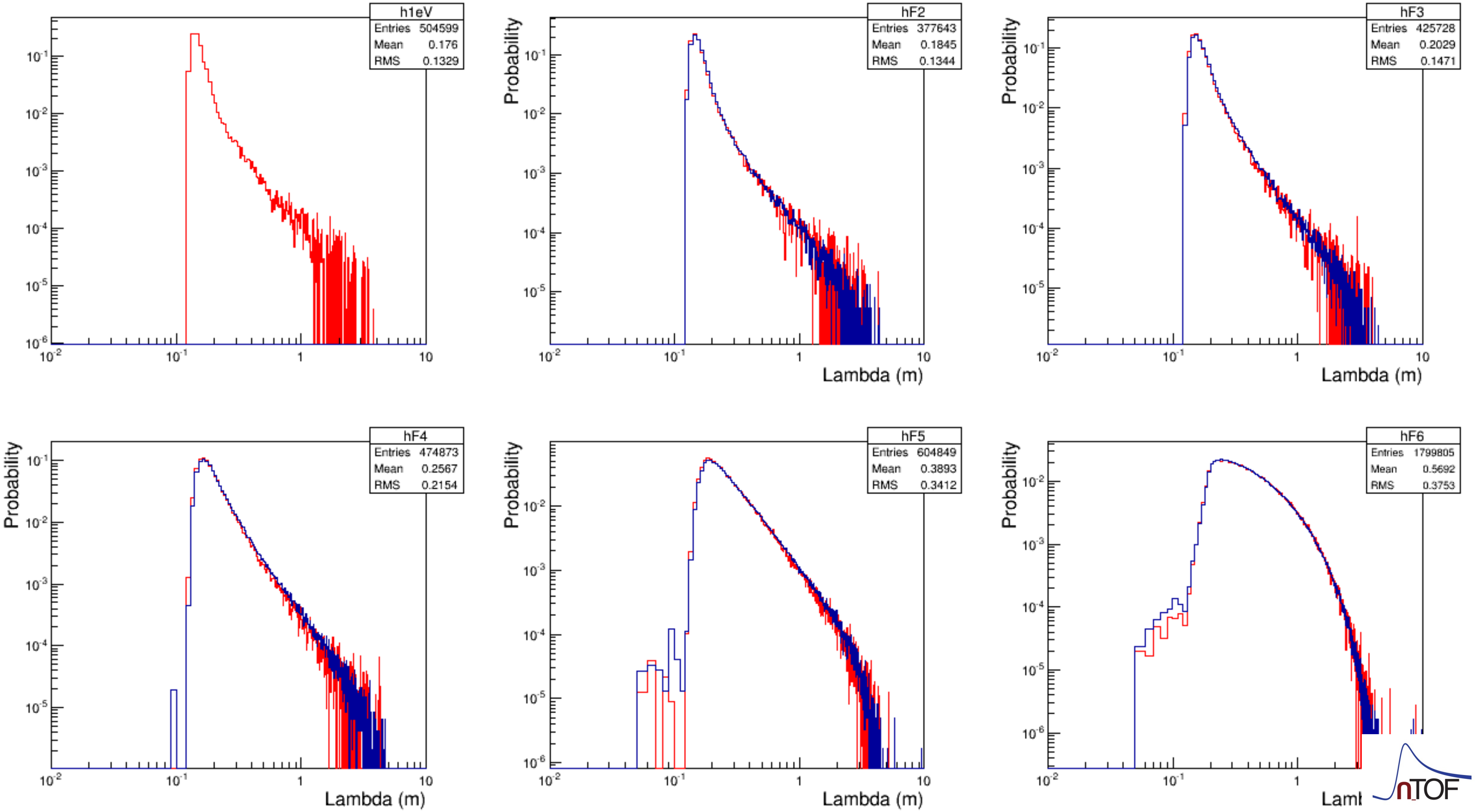


GEANT4 at EAR1
GEANT4 at TARGET
Neutron flux per pulse - $\frac{dN}{d\ln(E)}$
10^5
10^4
10^3
10^{-2} 10^{-1} 1 10 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
Neutron energy (eV)



GEANT4 at EAR2
GEANT4 at TARGET
Neutron flux per pulse - dN/dln(E)
Neutron energy (eV)

Equivalent distance



Results – EAR1

Resolution function, comparison with FLUKA